Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp803-804

Potential Characterization of Interconnect Corrosion by Kelvin Probe Force Microscopy

Masako Kodera[1], Yasuhito Yoshimizu[1] and Kanae Uchida[2]

[1] Corporate Research and Development Center, Toshiba Corporation
8 Shinsugita-Cho, Isogo-ku, Yokohama,
Kanagawa 235-8522, Japan
Phone: +81-45-776-5577 E-mail: masako.kodera@toshiba.co.jp
[2] Semiconductor Company, Toshiba Corporation
800, Yamanoisshiki-Cho, Yokkaichi, Mie 512-8550, Japan

1. Introduction

In the developing history of LSI fabrication, corrosion is always a major concern. Due to the emergence of copper interconnect, corrosion protection technique becomes especially essential because Cu is easily dissolved in a process solution such as etching solvent, CMP slurry, and so on. Moreover, BEOL-based memory applications for instance MRAM [1], PRAM [2], and RRAM [3] are currently being developed and reported. Since corrosion in interconnect can be easily spread to other connected structures that are composed of metal or conductive materials, the importance of understanding corrosion mechanism is much more increasing. One of the big mysteries about corrosion is why a particular interconnect is corroded faster than the surrounding ones. For example, a metal line attached to a wide metal pattern such as an electrical pad is faster corroded than the other ones. Such lines are also faster electroplated than others. Moreover, it is reported that interconnect attached to a transistor is decayed by photo corrosion [4]. However, some corrosion even occur in the dark condition, indicating that photo corrosion does not correspond to all corrosion phenomena. Thus, it is still unknown why corrosion easily occurs at the line connected to pads or transistors. Hence, we thought that some unrevealed cause of corrosion existed. A new characterization technique using Kelvin probe force microscopy (KFM) was proposed [5]. KFM is founded on atomic force microscopy (AFM), which allows us to obtain not only topographic images but also potential images based on Kelvin method [6]. Shima et al. observed Cu interconnect in Sematech test pattern by KFM, and found relation between the KFM potential between corrosion in a H_2SO_4 aqueous solution [5]. However, potential with finer pitch interconnect attached to a transistor has not been reported yet.

In this study, we tried to clarify the effect of the interconnect potential on corrosion by KFM measurements with fine pitch tungsten interconnect pattern that is fixed to pads and/or transistors.

2. Experiments

A test vehicle that had tungsten line patterns connected to pads and/or transistors was prepared on a 300 mm diameter silicon substrate. The minimum width of the lines and the spaces is less than 50 nm. Two interconnect test patterns shown in Fig.1 were used for the KFM evaluation. Sample A consists of one tungsten line connected to four electrical pads, surrounded by the fine and dense floating lines and spaces. Sample B consists of one tungsten line connected to four pads and a MOS transistor. These samples were formed by damascene method composed of dry etching of the dielectric film, tungsten film deposition, and CMP technique. One piece of the sample A and sample B were treated in a wet solution. In addition, corrosion observation by secondary electron microscopy (SEM) was previously performed, and it was found that plurality of plugs connected to the pad and/or the transistor by way of the center line were corroded. To the contrary, other plugs attached to the floating lines were not deformed at all.

The KFM and AFM images were obtained by scanning probe microscope (SII Nano Technology Inc., S-image) employing rhodium-coated silicon cantilever and 0V bias for KFM. The observed regions are shown in Fig.1 by the dashed lines. All observation was performed at room temperature in the atmosphere.

3. Results and Discussion

Figures 2 (a-c) show top views of KFM image of the samples, and Figs. 2(d-f) show lateral potential distributions enclosed with the dashed line in Figs. 2(a-c). The lighter color in Figs. 2(a-c) indicates the higher KFM potential. The higher KFM potential corresponds to the lower work function, indicating its easiness of corrosion [5]. The conditions of the samples are summarized in Table 1.

Table 1 Conditions of samples in Figures 2 and 3

Figure number	Sample	Wet treatment
2(a), 2(d), 3(a)	A	Without
2(b), 2(d), 3(b)	A	With
2(c), 2(f), 3(c)	B	With

In Fig. 2, the line connected to the pad and/or the transistors exists at the center of the pattern. Every center area in the dense lines and spaces pattern (L/S) has higher potential than the surrounding pattern in Fig. 2. The increased amount of the potential in the center area is about 200 mV, 50 mV, 100 mV in Fig. 2(d), 2(e), or 2(f), respectively. Comparing these potentials, the wet treatment is effective to decrease the potential. The source of this high KFM potential in the center area can be attributed to the electron charge up through dry processing [8] during fabrication of the plugs and/or the transistor. Moreover, it is supposed that a part of electrons stored in the high potential region is released through the wet treatment. Furthermore, the detailed observation revealed that the metal lines possess lower KFM potential than the dielectric region. In Figs. 2(a-c), it is also confirmed that every extracted lines outside the L/S pattern possess lower KFM potential than the surrounding dielectric film. For example, the potential of the extracted line in Fig. 2(a) is 74 mV lower than that of the dielectric film. These lower KFM potentials in the W wiring can be explained by oxidation of W surface, since it is reported that KFM potential of the oxidized Ti surface is lower than that of non-oxidized Ti surface [7].

Figure 3 shows top views of AFM images obtained by observation of the same samples in Fig. 2. It is confirmed that the extracted line connected to the pad and/or transistor becomes hollow by 20 nm. The mechanism of this depression can be explained as follows. Since the lower KFM potential at the extracted line is attributed to oxidation of W surface, this oxidized tungsten was easily removed and depressed by both CMP as well as wet treatment.

3. Conclusions

The fine-scale potential observation was performed by KFM using tungsten interconnect patterns in which minimum pitch is less than 50 nm. It is confirmed that the line connected to pads and/or transistor has peculiar KFM potential comparing to the surrounding pattern, and only the attached plugs to the line were corroded. This peculiar KFM potential may be due to electron charge up, and charged electrons can induce corrosion not only in the line itself but also in the connected structure. It is also revealed that the high potential in the L/S pattern can be decreased by a wet treatment. Thus, we can successfully demonstrate that the potential of interconnect has a strong influence on interconnect corrosion, and that KFM observation is useful even with less than 50 nm pitch pattern.

Acknowledgements

We would like to express sincere thanks to Dr. Shima, Ebara Corporation for the fruitful discussion in the KFM technique. We would like to great thanks to the technical staff in SII Nano Technology for their support through the KFM observation.

References

[1] S. Fukami, T. Suzuki, K. Nagahara, N. Ohshima, S. Saitoh, R. Nebashi, N. Sakimura, H. Honjo, K.Mori, E. Kariyada, Y. Kato, K. Suemitsu, H. Tanigawa, K. Kinoshita, S. Miura, N. Ishiwata and T.Sugibayashi, Extended Abstr. SSDM (2010) E-7-1.

[2] D. Kau, Extended Abstr. SSDM (2010) E-8-1.

[3] K. P.Chang, H. T. Lue, K. Y. Hsieh and C. Y. Lu, Extended Abstr. SSDM (2010) E-8-2.

[4] Y. Homma, S. Kondo, N. Sakuma, K. Hinode, J. Noguchi, N. Ohashi, H. Yamaguchi and N. Owada, J. Electrochem. Soc. **147(3)** (2000) 1193.

[5] S. Shima, K. Tokushige, A. Fukunaga and M. Tsujimura, Advanced Metallization Conference (2009) 441.

[6] M. Nonnenmacher, M. P. O'Boyle and H. K. Wickramasinghe: Appl. Phys. Lett. **58** (1991) 2921.

[7] Application Brief, SPI No.13 (2002), SII Technology Inc.

[8] J.-E. Lee, J.-H. Chung, H. Park, T. W. Seo, S.-H. Park, U-In Chung, G.-W. Kang and M.-Y. Lee, IITC (1999) 273.

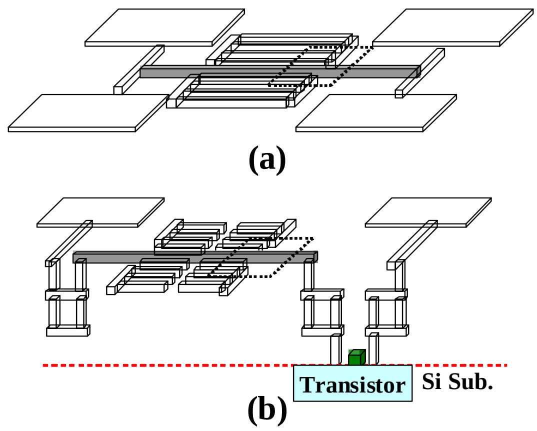

Fig. 1 Structure of test vehicle. (a) Sample A. (b) Sample B.

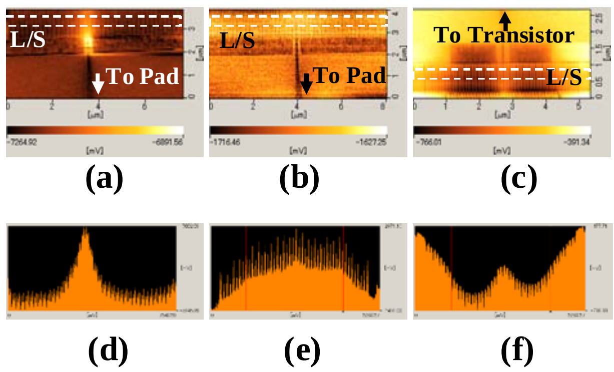

Fig.2 KFM images at the border of lines and spaces pattern. (a)(d) Sample A without wet treatment. (b)(e) Sample A with wet treatment. (c)(f) Sample B with wet treatment.

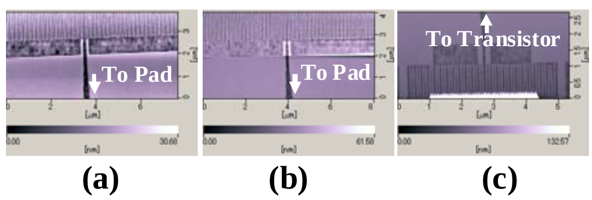

Fig.3 AFM images in the same position.
(a) Sample A without wet treatment. (b) Sample A with wet treatment. (c) Sample B with wet treatment.